

## 3.2 PACIFIC SECTOR

Coupled atmosphere/ocean processes across the Pacific Ocean region exhibit perhaps the most pronounced interannual-to-decadal variability anywhere on earth, and their influences on climate encompass much of the globe and affect much of its human population. A basic understanding of ENSO has been developed, which has led to routine ENSO forecasts with useful skill at ranges approaching one year. Many aspects of ENSO still are not well understood, however, including its decadal modulation. Our understanding of coupled decadal variability in the Pacific sector and its predictability is rudimentary. Several plausible theories invoke very different atmospheric, oceanic, and coupled mechanisms. However, we lack long and comprehensive data records, particularly from the ocean, to test these theories or quantify many of the pathways and processes that regulate transport and exchanges of heat and freshwater in the coupled system. For example, our understanding of atmospheric processes such as deep convection and ocean processes such as diapycnal mixing must improve if we are to rely on the predictions of coupled models. More complete discussions of the hypotheses and dynamic issues with climate variability in the Pacific sector appear in the PBECS Prospectus and Plan; we only summarize those discussions here.

Accurate predictions of the effects of the 1997—98 El Niño demonstrated that we have achieved significant skill in forecasting the evolution of the tropical Pacific and its extratropical teleconnections at least six months ahead, especially once a warm event has begun. By the first months of 1997 (when strong westerly winds were first observed in the western equatorial Pacific), several models were suggesting that a moderate or larger El Niño was developing and would grow through the rest of the year. By mid-1997, models were forecasting the evolution over the next six months quite realistically. This ability is a clear application of the successes made possible by a concentrated effort that combines long-term observations, modeling, and assimilation techniques. At the same time, much before the initiating winds, even the best models had only a slight ability to forecast the onset of the 1997 event, and none predicted the extremely large amplitude it would reach. For situations less dramatic than the growth stage of a major El Niño, our skill at predicting the smaller variations of tropical Pacific SST remains relatively weak. Although many models simulate the growth, propagation, and maintenance of El Niños, the dynamic and thermodynamic balances among upwelling, zonal advection, meridional advection, diapycnal mixing, and air-sea heat fluxes that these models display are different. Even the role of the equatorial waves so prominently observed in sea level and thermocline depth is uncertain. We do not have a clear understanding or description of what an El Niño precursor state looks like. Therefore, the fact that models failed to predict the extreme amplitude reached by the 1997—98 event is not surprising. Similarly, although some El Niños have quickly reversed into a strong La Niña state (e.g., 1986—87 evolving into the 1988 La Niña), others have not (e.g., 1991—92) and we do not understand the conditions that govern these changes.

Although scientists have known for 30 years that the ENSO cycle is a coupled phenomenon, the details of the coupling mechanisms are poorly observed. Equatorial surface zonal winds are very sensitive to the zonal SST gradient, and these winds in turn modulate the thermocline depth, which is a major influence on SST through upwelling that brings thermocline water in contact with the surface layer. SST cooling through upwelling is determined by vertical mixing in a region of strong shears and property gradients, however, so the efficiency of upwelling-induced cooling is an extremely complex interaction of many processes that are difficult to observe or diagnose. Further complicating the observational picture is the existence of large-amplitude variability on short time

scales, such as ubiquitous tropical instability waves. Modeling these processes also has been challenging because the above-thermocline layer can be quite thin relative to the vertical resolution of most basin-scale models, so vertical exchanges often are parameterized rather crudely. The CLIVAR strategy for resolving these issues is a program of continued model experimentation and improvement (see Section 2.3.1) coupled with a significantly improved observing system including short-term, intensive observational studies to examine the processes that bring thermocline-level water to the surface. The aim is a data assimilation synthesis that would accurately represent the effects of the complex mix of processes that change equatorial SST and thereby foster ocean-atmosphere coupling.

Just as predicting individual El Niño events is important, the envelope of ENSO activity has societal impacts. ENSO has varied greatly on decadal time scales. Many hypotheses have been proposed to explain this variability, including the effects of (ocean-reddened) atmospheric noise or nonlinearity in ENSO itself (for example, how oceanic modifications by one El Niño affect the next event). Many models suggest that the background state of the equatorial thermocline is a key factor in determining the nature of an El Niño event because it is such a strong influence on the efficiency of upwelling to cool SST. Observations show that the slope of the equatorial thermocline is linearly related to the equatorial zonal wind on time scales of a few months, although its zonal mean depth is not clearly connected to equatorial wind forcing. Instead, changes of mean thermocline depth may be caused by winds on larger meridional scales (the entire tropics) that change the net Ekman divergence from the tropics and thereby produce a general shoaling or deepening in the upwelling region on slower time scales. This process is one possible mechanism by which events outside the tropics can have an effect on the decadal envelope of the ENSO cycle.

Other theories backed by some suggestive observations and model runs argue that the characteristics of the water in the equatorial thermocline are determined by air-sea interaction in the southeast and northeast subtropics, where the water is subducted into the thermocline. These properties are carried by the geostrophic circulation, usually via low-latitude western boundary currents, to the equator, where they are upwelled. If there is substantial variability influencing the characteristics of the subducted water, and if these characteristics survive the 10-year or so advective pathway, they may modulate the properties of the upwelled water and affect the slow evolution of the ENSO cycle. Finally, weak signatures of mid-latitude decadal wind anomalies reaching down into the tropics may have their tropical effects magnified by the sensitivity of equatorial SST gradient-zonal wind feedbacks. The CLIVAR strategy for understanding decadal modulation of ENSO and its potential predictability involves improving analyses of basin-scale fields so that the slow evolution (including property advection) can be viewed as a whole. This goal will be achieved through major enhancements to the observational database that is available to be assimilated into models (especially ARGO profiles; see Section 2.2.4), specific enhancements such as monitoring of western boundary currents and equatorial Ekman divergence (see Section 3.2.4), and improvements to the wind forcing of the assimilating models as scatterometer records lengthen.

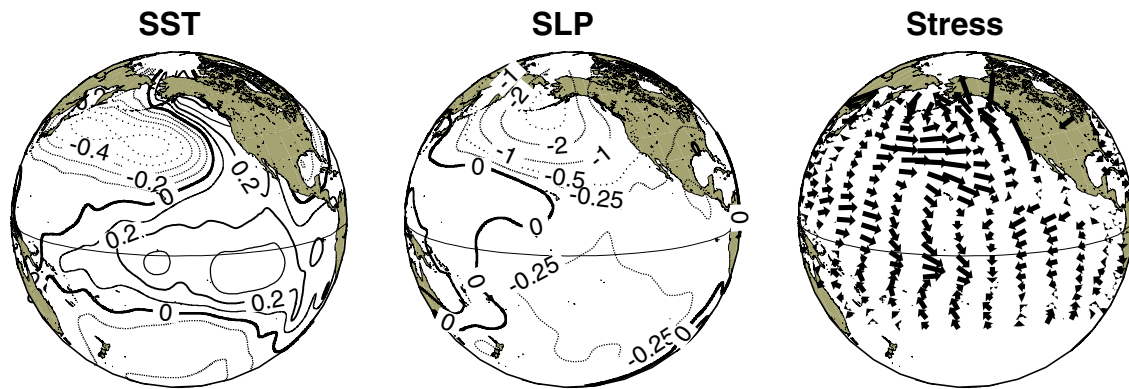
The Pacific sector also experiences significant decadal variability in mid-latitudes, the persistence of which contributes to the skill of operational climate predictions for North America. The PDO is a complex of phenomena, including very broadscale wind and SST anomalies, that comprises the most energetic low-frequency mode seen in the few long oceanic time series around the basin and has important effects on salmon fisheries and decadal variations of snowpack in the Pacific Northwest. The spatial patterns of the PDO resemble those of ENSO (see Figure 3.2). One interpretation is that

the PDO is simply the low-frequency modulation of the ENSO cycle, which is spatially broadened because lower frequency Rossby waves have wider meridional scales.

Some coupled GCMs develop a fully coupled mid-latitude basin mode, however, in which the key process is variation of heat transport by the Kuroshio that feed back to modify the wind-stress curl that produces the subtropical gyre. In these experiments, the time scale of the oscillation is set by the transit time of Rossby waves (driven by the wind-stress curl) that set up the Kuroshio (about 20 years). A difficulty with this hypothesis is that many AGCMs suggest that the mid-latitude atmosphere is not sensitive to mid-latitude SST, which implies that the key feedback would not occur. Resolving this issue is a subject of current research; some observations appear to show that the sensitivity resides in the response at synoptic time and space scales in the Pacific storm track, which at present are not well resolved.

Other hypotheses for decadal variability in the North Pacific point to strong air-sea heat exchange in the Kuroshio Extension region, where cold dry continental air flows out over the relatively warm water of the Kuroshio. If the oceanic heat transport or the patterns of winter outflow vary, the change in heat flux could be substantial. Finally, some studies support the point of view that the PDO cannot be statistically distinguished from simple oceanic reddening of atmospheric noise; as in other regions, the shortness of the instrumental record relative to the decadal periods of interest makes statistical confidence difficult to obtain. Because the 15 years of CLIVAR will not lengthen the observed record sufficiently to produce unambiguous statistical confidence, the strategy instead is to gather observations and to test and improve the models to be able to evaluate physical hypotheses.

# Pacific Decadal Oscillation



# El Niño Southern Oscillation

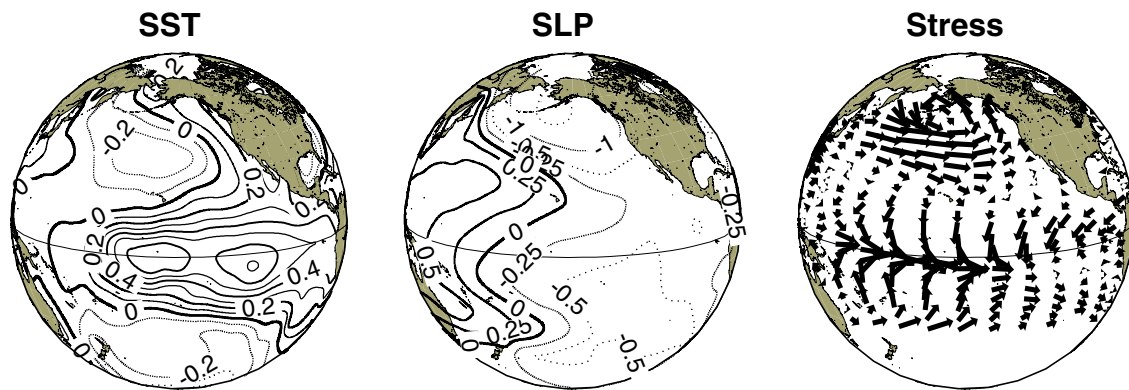


Figure 3.2. Patterns of sea-surface temperature (SST), sea-level pressure (SLP), and wind stress associated with the PDO (upper) and with ENSO (lower), from Mantua et al. (1997).

Central to the implementation of Pacific CLIVAR is collection of a comprehensive three-dimensional set of observations of the entire upper Pacific Ocean including its boundary currents and air-sea fluxes as well as the overlying atmosphere, over a period of 15 years. Also central to implementation is the use of data-assimilation modeling to quantitatively diagnose the mechanisms involved in climate variability. To date, the decadal modulation of ENSO, the dynamics of ENSO, and decadal variability in the Pacific Basin have been identified as Pacific climate phenomena of immediate interest; implementation plans have been driven largely by the desire to better understand these phenomena. In considering these phenomena, Pacific CLIVAR must be able to observe the variability of the upper 1500—2000 m of the ocean and overlying atmosphere, resolve transport pathways, and clarify the causal relationships associated with the observed variability.

Much of the sampling required will be provided by broad, basin-scale sampling. Within the Pacific basin, there will be some unique elements of the observing system; in addition, specific regions that are important to climate variability must be addressed with more complete observations than those of the global program. Finally, process studies of shorter duration are anticipated that will strengthen our understanding of important physical processes such as upwelling, mixing, cloud feedbacks, and deep convection.

### 3.2.1 Goals of Pacific CLIVAR

The long-term goals of Pacific CLIVAR are as follows:

- Better understand Pacific basin-scale atmosphere-ocean variability, its predictability on seasonal and longer time scales, and anthropogenic impacts, with particular attention to ENSO and its decadal variability and to the PDO.
  - Document time-varying temperature, salinity, and currents in the upper ocean at 300 km, 10-day resolution over the entire Pacific basin north of 40°S for a 15-year period, with higher resolution in boundary currents and near the equator. Use an ocean data assimilation model to provide a three-dimensional, time-dependent gridded analysis of this data.
  - Document time-varying vertical and lateral fluxes and air-sea exchanges of heat, freshwater, and momentum over 15 years, not only on the basin scale but also with good spatial resolution in the boundary and equatorial regions of the Pacific basin.
  - Document the variability of the atmosphere over the Pacific over 15 years, with resolution of synoptic weather events and the vertical structure of the lower atmosphere, to improve the accuracy of the specification and our understanding of air-sea coupling and to examine the role of episodic forcing events.
- Improve physical parameterizations in OGCMs, AGCMs, and NWP models used to simulate the Pacific through the use of process studies and by using ocean data assimilation to identify apparent systematic errors in the atmospheric forcing of the ocean or the assimilating ocean model.

Existing and new CLIVAR-supported global observations, as well as empirical and modeling studies, provide the context for Pacific CLIVAR and are key to implementing it. In addition, the scientific and coupled modeling issues that are at the heart of Pacific CLIVAR are being studied. The strategy will be to integrate these efforts and add supplemental observations and studies to understand climate variability in the Pacific sector. These supplemental efforts will include broad-scale sampling, fielding of regionally focused programs that are unique to the Pacific, and conducting process studies to address shortcomings in understanding and parameterization. All elements will be brought together in the framework of assimilative modeling. Comprehensive analysis, testing, and improvement of coupled models are anticipated.

This effort will require modelers, analysts, and data gatherers to work together. An annual meeting will be held to build the desired interactions. This meeting will have the goals of attracting and fostering interaction with the broad community of scientists working on Pacific climate variability and showcasing Pacific CLIVAR data sets. In conjunction with these meetings, Pacific CLIVAR will develop a modeling interface aimed at promoting analysis of decadal variability in coupled models and improving physical parameterizations in AGCMs and OGCMs.

### 3.2.2 Sustained Observations—Pacific Basin Extended Climate Study

PBECS which is described at length in the PBECS Plan is a long-term (2001—2015) study of the main climate phenomena of the entire Pacific basin, including ENSO, ENSO's decadal modulation, and the PDO. Its foundation is a collection of basin-wide observing components, selected time series and regional arrays to define critical climate elements, and a program of data assimilation intended to synthesize these observations and provide a framework for testing models and hypotheses about climate dynamics. The main components of PBECS are as follows:

- *ARGO*. An array of temperature and salinity profiling floats on a 3° grid extending from the Aleutian Islands to 40°S is central to PBECS goals.
- *High-resolution XBT*. PBECS depends on continuation of the existing Pacific VOS-based high-resolution XBT/XCTD shown in Figure 2.2 and implementation of the two new north-south lines (PX4 and PX21). A significant fraction of these lines also should support upgraded surface meteorology and flux observations.
- *Assimilation*. An ocean data assimilation effort with adequate computing and staffing resources is important to syntheses of all PBECS data and to test dynamic hypotheses.
- *TAO/TRITON*. The present TAO/TRITON array of wind and subsurface temperature measurements should be maintained to the high temporal resolution needed in the equatorial region. Moorings with current observations along two meridional TAO lines should be added to describe the Ekman limb of the shallow overturning circulation. The possibility of adding near-surface salinity observations to TAO is under study.
- *ENSO Observing System*. Drifter observations of surface circulation and SST, tide gauges, and (until ARGO is at full strength) broad-scale VOS XBT sampling should be continued.
- *Flux reference moorings*. Two to four moored surface buoys providing time series of surface fluxes and meteorology as well as subsurface temperature, salinity, and horizontal velocity are needed in regions of special interest, including the Kuroshio Extension, Ocean Station P (50°N, 145°W), the central North Pacific (a PMEL mooring is at 35°N, 165°W), off the west coast of North America (perhaps in coordination with other coastal weather or marine ecology studies), and the stratus region off the west coast of South America (a NOAA-funded buoy is at 20°S, 85°W). These moorings will contribute to the international network of surface-flux reference sites and ocean time-series stations.
- *Ocean time series*. At select locations, the United States should maintain long time series of oceanic variability over the water column. The Hawaii Ocean Time series (HOT) is a unique, multidisciplinary time series station off Hawaii that is gathering ocean thermodynamic profiles and a variety of biological and chemical measurements. It is an important element in the Pacific of the growing intersection of interest between CLIVAR and the national ocean carbon program. At other locations, moorings, autonomous vehicles, or frequent occupation by a ship may be used to observe the temporal variability and vertical structure of temperature and salinity variability, currents and transports, and biological and chemical quantities. Siting of these time-series stations is under discussion with international partners.
- *Enhanced atmospheric monitoring*. Many radiosonde and profiler sites around the Pacific basin that nominally take soundings at least daily apparently are not getting soundings into the operational data stream on a regular basis. Pacific CLIVAR priorities will be to facilitate timely communication of all available upper-air data; to reinstate radiosonde launches at Galapagos, Midway, Wake Islands, and at least one radiosonde site in the Line Islands (2—8°N, 157—162°W), which provide a unique natural cross-section across the central Pacific ITCZ; and to implement regular GPS-sonde sampling from the TAO deployment cruises and investigate the feasibility of deploying radiosondes from high-resolution VOS lines.
- *Repeated hydrography*. Two zonal and two meridional hydrographic lines should be occupied every 6—10 years. Present planning with the international carbon program is for lines along 30°N, 32°S, 110°W in the South Pacific, and 150°W in the North Pacific.
- *Western boundary currents*. Time series of heat and mass transport are needed in key western boundary currents implicated in decadal variability, especially the PDO, and decadal modulation of ENSO. Beginning regular measurement of the Mindanao Current and New Guinea Coastal Undercurrent both of which are sources of water that form the equatorial

thermocline and are potentially important to decadal modulation of ENSO is critical. Effective technologies and methods for this measurement have not been identified; work to develop these methods is needed. The boundary currents off Japan, Taiwan, and eastern Australia are monitored by high-resolution VOS/XBT sections, but the frequency of sampling should be increased.

The duration and comprehensive nature of PBECS which includes atmospheric, oceanic, and coupled studies that use modeling, empirical, and observational approaches dictates continuing oversight, evaluation, and guidance of the program. Thus, PBECS will be planned nationally by the Pacific Sector Implementation Panel, which also will participate in international CLIVAR Pacific implementation meetings to review and coordinate activities within PBECS.

### **3.2.3 Other Regional and Process Studies**

We envision several process experiments and regional studies that will be required to meet the program's goals. Regional studies are appropriate in places where a combination of processes is of particular climate interest and the foregoing basin-wide observations may not be adequate to define the phenomena. The cold tongue ITCZ and stratocumulus cloud deck regions of the eastern Pacific, the bifurcation of the North Equatorial Current at the western boundary, and the Kuroshio Extension are special regions that may warrant regional studies. Process studies focus on a specific phenomenon that is important in more than one region. The dynamics of stratus clouds and convection, oceanic mixing, low-level jets, and equatorial upwelling are potential subjects of process experiments.

Examples of regions and processes that are candidates for special studies are discussed below. In some cases, CLIVAR may augment or approve studies that already are planned. In others, a general need for further study has been identified, but no plans have been developed.

#### *The Eastern Pacific*

Coupled model studies show the sensitivity of the coupled climate system to stratus clouds in the eastern Pacific. The strong meridional SST gradients between the eastern Pacific cold tongue and the warm pool to its north, and the intertropical convergence zone in the atmosphere above, in part reflect strong local coupling. There is evidence of organization of SST anomalies on a space scale that is comparable to the width of the basin and on time scales that are longer than the characteristic thermal damping time of the mixed layer. Coupled model simulations of SST in the western hemisphere warm pool, which extends from the eastern Pacific waters off Central America to the Gulf of Mexico, do not have the desired quantitative accuracy.

Smaller-scale regional variability escapes the resolution of basin-scale OGCMs but may be significant in the upper ocean heat, mass, and momentum budgets. For example, over the eastern Pacific, the region up to a few hundred kilometers off Central America generally is very warm but can cool rapidly in response to winter northerlies blowing through gaps in the American cordillera. South of the equator, the annual coastal upwelling signal has been cited as important for the development of much larger-scale phenomena, but the processes by which the narrow coastal features might influence the larger scale have not yet been clearly elucidated. Present basin-scale OGCMs handle these near-coastal signals poorly. The question of closure of the equatorial and tropical current systems in the east Pacific particularly the fate of water flowing eastward in the

North Equatorial Countercurrent and Equatorial Undercurrent is obscure. To date, these currents have been understood only as features of the broad central Pacific, far from boundaries. Similarly, the source of water upwelled in the equatorial cold tongue, the depth from which it originates, and the meridional extent of the upwelling cell have not yet been established, nor has the upwelling water been traced back to the surface in extratropical regions, as theory has suggested. Questions about the closure of current systems in the east Pacific speak to the most fundamental aspects of the ocean circulation; they will become tractable as the community develops confidence in the performance of OGCMs in the tropical eastern Pacific.

The Eastern Pacific Investigation of Climate Processes in the Coupled Ocean-Atmosphere System (EPIC) is a process study to improve the description and understanding of processes that are responsible for the structure and variability of the extensive boundary-layer cloud decks in the southeastern Pacific. The results of EPIC are expected to improve the performance of coupled ocean-atmosphere models over the eastern Pacific and result in improved short-term climate analysis and prediction system for the Pan American region. The scientific objectives of EPIC are as follows:

- To observe and understand the ocean-atmosphere processes that are responsible for the structure and evolution of large-scale heating gradients in the equatorial and northeastern Pacific portions of the cold-tongue/ITCZ complex (CTIC)
- To observe and understand the dynamic, radiative, and microphysical properties of the extensive boundary-layer cloud decks in the southeasterly tradewind and cross-equatorial flow regime; their interactions with the ocean below; and the evolution of the upper ocean under the stratus decks.

Descriptive and diagnostic studies of the oceanic and atmospheric boundary-layer structure and interfacial fluxes in the CTIC provide a large-scale context for process-oriented field studies in EPIC. CTIC studies were conducted in the equatorial Pacific at 125°W during 1997. Enhanced monitoring of the CTIC in the monsoon regime further to the east continues some elements from the pilot studies, initiates new elements, and provides spatial and temporal context for future EPIC activities.

While US CLIVAR was being organized, a group of investigators set out a plan for EPIC (see EPIC Scientific Steering Committee 1999) and its first field phase. EPIC 2001 is a one-month intensive observational examination of the CTIC, with an exploratory stratus deck component (see Raymond et al. 1999). US CLIVAR seeks to accelerate progress in improving simulations of the CTIC and the stratocumulus regime through informal groups of EPIC observers and modelers who will synthesize results from EPIC enhanced monitoring and intensive observations.

A second phase of EPIC is being planned as a process experiment to concentrate on interactions between the marine boundary layer and South America on a variety of time scales. EPIC Phase II (2003—2005) will be a larger international study and an element of VAMOS within international CLIVAR. Because of its international nature and potential scope, the Pacific and Pan American panels will nationally plan this second phase of EPIC. The scientific goal is to look at possible covariations and feedbacks involving stratus clouds and boundary layer properties with deep convection over the South American continent. Deep convection over South America might affect the stratus by modulating compensating subsidence and/or free-tropospheric humidity and temperature. If this process affects radiative cooling within the PBL, it also would affect the strength of the subtropical high, near-coastal winds and coastal upwelling, which on longer time

scales might feed back on the convection. Diurnal through synoptic time scales of variability could be addressed in such an experiment. South American countries may provide considerable support, with San Felix Island off Chile and ships measuring horizontal divergence and cloud/boundary layer structure. Coastal and mountain stations could help quantify the role of orography and the links between land and ocean. More preliminary study is needed to identify whether the stratus-convection link is clear enough to be of major climate importance.

### *Western Boundary Currents*

Western boundary currents have been identified as of high interest within the Pacific sector. Transport variations in the East Australia and Kuroshio Currents play critical roles in some theories of decadal variability by modulating heat transport to mid-latitude storm-track regions. Present high-resolution XBT sections traverse each of these currents at two latitudes, but the low frequency, limited depth, and lack of direct velocity of observations limit their use for climate purposes. We hope that scientists from Japan, Taiwan, and China will continue to measure the Kuroshio at low latitudes.

The Indonesian Throughflow is the main conduit between the tropical Pacific and Indian Oceans. The climate requirements for monitoring it can be met with the US-Australian high-resolution XBT section; we recommend continuing support for this effort.

Tropical western boundary currents in the Pacific are poorly known, but limited evidence suggests that they fluctuate significantly on short time scales and are important conduits between the equator where ocean-atmosphere coupling is direct and subtropical regions, where water properties are determined by air-sea interaction. Thus, these boundary currents are key in the study of decadal modulation of ENSO and decadal variability. Time series of mass, heat, and (ideally) salinity transport in the Mindanao Current and the New Guinea Coastal Undercurrent are needed to examine the importance of their variability to equatorial air-sea interaction. New technology and methodology, and perhaps a regional or process study, will be needed to develop cost-effective ways to monitor these currents.

Planning for sampling of the mid-latitude Kuroshio is further along because of pioneering work by Japanese oceanographers and the Kuroshio Extension System Study (KESS), a joint project of the United States and Japan. The design of KESS (summarized in the PBECS Plan) predates US CLIVAR planning, but its goal of clarifying how SST anomalies in the Kuroshio-Oyashio outflow region are created makes it an important contribution to CLIVAR. KESS is a five-year project that includes high-resolution subsurface velocity, temperature, and salinity measurements, as well as remote sensing and perhaps a Japanese TRITON buoy now being tested in the region. The focus is on variability of the western boundary current inflow, eddy-mean interaction, recirculation dynamics, and cross-frontal exchange. KESS will examine the upper-ocean heat budget by assimilating *in situ* and satellite observations into an ocean circulation model. Accurate regional forcing estimates are needed, and the addition of *in situ* meteorological buoys to serve as references for NCEP or other surface fields would greatly improve our ability to describe the upper-layer heat budget. Because KESS aims to elucidate important climate processes in the complex Kuroshio Extension region and because it is providing the information needed to design an affordable monitoring system, US CLIVAR should consider, in cooperation with Japanese scientists, augmentations to KESS that would significantly increase its utility for climate studies.

Because of the potential importance of the western boundary currents to coupled ocean-atmosphere interaction and tropical-extratropical pathways, interest in the Kuroshio extension region is likely to continue beyond KESS. A CLIVAR regional climate study in this area may be in order.

### *Equatorial Upwelling*

Equatorial upwelling is a central process in determining the SST variability in ENSO and perhaps decadal variability. Despite its importance, we have no direct measurements that allow us to know the mass and heat transports associated with equatorial upwelling, nor has there been a process experiment focused on upwelling dynamics. Sustained observations of the volume and temperature/salinity variability of water upwelled at the equator are needed to enable us to understand the relative roles of local winds and remotely driven changes in thermocline structure in determining equatorial SST variability. We do not know how to carry out this monitoring over the 15 years of CLIVAR. A process experiment focusing on equatorial upwelling would allow examination of parameterizations and model performance for processes associated with upwelling; it also could provide information with which to design a sustained observing system for equatorial upwelling. Pacific CLIVAR will encourage process studies that do this.

*We recommend a pilot study focusing on quantifying equatorial upwelling and developing the means to monitor it.*

### *Process Studies*

We anticipate that during CLIVAR, investigators or groups of investigators will organize field and modeling studies aimed at better understanding the physics of the ocean and atmosphere and improving physical parameterizations of processes in OGCMs, AGCMs, and NWP models used to simulate the Pacific.

### **3.2.5 Supporting Studies**

The Pacific CLIVAR research program also will be helped by insights and data derived from many other upcoming programs. A few salient examples:

- *The Consortium for Ocean Research and Climate (CORC)*. CORC is a long-term ocean-observation program in the central and eastern tropical Pacific. CORC focuses on the cold tongue, upwelling, and other branches of the shallow overturning circulation that are implicated by some theories in modulating the evolution of ENSO. Data assimilation modeling will be used to synthesize and maximize the value of the observations. Surface drifters focus on surface currents and heat advection with additional surface meteorology measurements. The VOS program includes basin-wide high-resolution XBT/XCTD sections (lines PX50 and PX51 in Figure 2.2 are now maintained, and PX5 will be added in 2001) and upgraded meteorology (IMET) packages to provide high-quality surface meteorological observations as reference for routine observations and analyzed flux fields. Until ARGO is online, an array of approximately 30 profiling floats is being maintained to supplement and extend TAO observations east of the dateline and to support EPIC. New technologies (an underway CTD and underwater gliders) are being explored for routine use. CORC predates US CLIVAR planning, but the commonality of their objectives and techniques suggests that closer coordination is desirable.
- *TRMM and future NASA projects*. The TRMM satellite should provide high-resolution swath observations of rainfall over the tropics and subtropics through at least 2003, improving our

understanding of tropical convection and precipitation distribution. Further space-based precipitation radars (and the CLOUDSAT/PICASSO-CENA mm-wave radar and lidar combination for active cloud remote sensing) are being planned.

- *The Hemispheric Observing System Research and Prediction Experiment (THORPEX)*. Pacific CLIVAR also may benefit from observations and observing system simulations from THORPEX, which is coordinated by USWRP. THORPEX will start in 2001, with a major field phase in 2003—2005; it will include a variety of supplemental surface and upper-air observations over the North Pacific Ocean. Depending on results from THORPEX, some of this operational enhancement of the atmospheric observational network over the North Pacific may become permanent.
- *The Global Air-Ocean In Situ System (GAINS)*. GAINS is being proposed to WMO and national funding agencies as a 50-year international program utilizing balloons drifting in the stratosphere as platforms for deploying dropsondes over remote oceanic locations. A pilot study is proposed for 2003.

### **3.2.6 Coordination**

Pacific CLIVAR depends on a blend of sustained observations synthesized within simple and complex models; a range of process and regional field studies; empirical analyses; and studies that use a spectrum of models, from simple to complex. There also are many non-CLIVAR programs contributing to and benefiting from US CLIVAR activities in the Pacific.

*To ensure coordination of CLIVAR Pacific and facilitate rapid dissemination of research results, we recommend an annual meeting focusing on climate-related topics in the Pacific.*